STATEMENT OF NEAL A. BLAKE, DEPUTY ASSOCIATE ADMINISTRATOR FOR ENGINEERING, FEDERAL AVIATION ADMINISTRATION, BEFORE THE HOUSE COMMITTEE ON SCIENCE AND TECHNOLOGY, SUBCOMMITTEE ON TRANSPORTATION, AVIATION, AND MATERIALS CONCERNING WIND SHEAR DETECTION TECHNOLOGIES, JULY 25, 1984

Thank you, Mr. Chairman. I am privileged to come before this Subcommittee today to discuss the Federal Aviation Administration wind shear program, and to specifically address wind shear detection technology. With me, are Mr. Kenneth S. Hunt, Director, Office of Flight Operations, and Mr. Willard Reazin, Manager, Procedures Division of the Air Traffic Service.

To begin I would like to briefly discuss the wind shear phenomena, give you a little background on prior FAA wind shear activities, and then address our current program and some specific systems, such as the Low Level Wind Shear Alert System (LLWAS), the Next Generation Weather Radar (NEXRAD), and its possible terminal derivative, and then discuss FAA plans for implementing the recommendations of the National Academy of Sciences' Low-Altitude Wind Shear Study.

The wind shear problem is certainly not new to the aviation community; the FAA has carried on an extensive program in this area since the early 1970's. Wind shear occurs throughout all strata of the atmosphere, but it is low altitude wind shear or wind variability that causes the greatest safety concerns. Wind shear becomes an extremely critical factor in aircraft operations in the airport environment when the aircraft is in the most susceptible mode: low altitude, low speed, and aerodynamically "dirty" or in a high drag configuration. Early in wind shear investigations and research it was thought that the approach and landing phase was the most crucial operation, because the majority of wind shear related accidents occurred during landing. However, a series of recent accidents and incidents have shown that wind shear can have dramatic effects on takeoff performance. The Joint Airport Weather Study conducted by the National Center for Atmospheric Research (NCAR) and the University of Chicago and co-sponsored by the National Science Foundation, the National Oceanic and Atmospheric Administration, the National Aeronautics and Space Administration (NASA), and the FAA, has convincingly demonstrated that certain types of wind shear can exceed the performance capability of the most modern airplanes.

Wind shear is caused by several atmospheric mechanisms: frontal movement (both cold and warm), sea breeze effects, gravity waves, the low level jet stream effect (predominately a central plains phenomena), and convective activity or thunderstorms that spawn gust fronts, downbursts, and the recently well documented microburst. Additionally, the National Severe Storms Laboratory in Norman, Oklahoma, has conducted extensive research and analysis the past few years on the "solitary wave" or detached gust front that can preceed convective storms by several hundred miles. Also, there are the orographic or mechanical shears, such as mountain waves, the Santa Ana type winds, and shears induced by large structures, tree lines, and irregular terrain features. Wind shear can take many forms, it can be insidious or abrupt; and an unexpected encounter by a pilot can sometimes be disastrous.

The Federal Aviation Administration conducted an intensive research and development wind shear program from 1975 through 1980. Objectives of this program included: the characterization of wind shear; definition of the hazards; improvement in wind shear forecasting; investigation and testing of wind shear detection techniques and equipments; and research, through piloted simulations, on airborne systems and techniques that could aid the pilot in coping with wind shear encounters. An early result from this program was the incorporation in 1978 of frontal wind shear forecasts into area and terminal forecasts by the National Weather Service (NWS). And more recently Dr. Theodore Fujita of the University of Chicago, as a part of the Joint Airport Weather Study, developed techniques for identifying the atmospheric mechanisms that are used to forecast microburst occurrence. A major part of our early wind shear program was the evaluation of wind shear detection technology. We devoted considerable resources to the development, testing, and evaluation of ground-based wind shear sensors.

Ground-Based Wind Shear Sensors:

The simplest and most straightforward sensor is the anemometer. Obviously it can only measure wind speed and direction "in situ" and cannot be used for sensing of wind at higher levels. Its advantages are reliability, maintainability, and its data are easily processed by computers.

Microbarographs or pressure jump detectors were tested at three locations: Dulles, Chicago, and Atlanta. Tests on pressure sensors were inconclusive, and though effective in detecting some shear conditions, their use cannot guarantee recognition of all atmospheric conditions that cause hazardous wind shear. The systems tested were subject to excessive false alarms, and adequate coverage for an airport requires a high density network of sensors.

Acoustic radar or Sodar is another technology that was examined. The acoustic radar can measure winds above the surface to a height of approximately 500 meters, but it is limited in sensing volume and has no scanning capability. A serious disadvantage of acoustic devices is that they are strongly affected by noise from heavy rain, high surface winds, and aircraft engines. Providing full coverage for a large airport in all likelihood would require at least one or more sensors in every approach corridor, an airport like Chicago's O'Hare might require up to 12 sensors.

Lidars, both frequency modulated continuous wave and pulsed, are very effective wind measurement sensors. The FAA has employed a low power, FM-CW laser Doppler velocimeter as both a wind shear and wake vortex detector. Lasers suffer substantial attenuation in fog, rain, and snow. Their main advantage is the capability to operate in clear air and achieve accurate measurements from the backscatter from small particulates normally found in the atmosphere. FM/CW lasers are effective to approximately 2,500 feet and NOAA's Wave Propagation Laboratory has measured winds in clear air at a range of 18 kilometers with an experimental pulsed laser Doppler velocimeter. Lasers provide good volume coverage and have scanning capability. Their major disadvantages are signal attenuation in bad weather, cost, and the high computational capability required for near real-time operation. The Royal

Aircraft Establishment, Bedford, U.K., has developed and flight tested an airborne lidar. The system was developed as a true airspeed sensor, but has demonstrated the ability to provide approximately 4 seconds of warning time to the pilot in significant shear situations. This system was flown in an HS-125 during the Joint Airport Weather Study. Should it prove possible to extend the range and warning time of the airborne lidars this may be a viable and effective airborne answer to the wind shear problem. FAA is working with NASA to develop a research program on airborne sensors for low altitude wind shear detection.

Infrared Radiometry has been proposed as a candidate wind shear detection system. IR Radiometers measure temperature differential in the atmosphere. Experimental ground and airborne systems have been developed and tested. During the Joint Airport Weather Study Program an airborne system was utilized in some of the experiments. Based on the analysis of the JAWS data, temperature differences are not reliable indicators of microburst occurrences. No definitive temperature change could be established in the microburst data; the change could be plus or minus and the range was generally from 1 to 3 degrees. Additionally, infrared devices, like lasers, suffer substantial attenuation in rain and snow.

Doppler weather radar is the last major sensor that we have investigated. I will be discussing our program in this area later in the presentation.

In parallel with this activity our flight operations and training people conducted pilot education and awareness programs, such as the General Aviation Safety Seminars and issuance of operations bulletins to our principal operations inspectors. In 1976, Advisory Circular 00-50 "Low Level Wind Shear" was published and then updated in 1979. The information and guidance contained on this advisory circular is sound and has proven operationally effective. We are currently working with the Air Transport Association Wind Shear Task Force on a revision to AC 00-50A "Low-Level Wind Shear" to incorporate recent meteorological findings and refinements to pilot procedures.

Wind shear profiles developed in the FAA, Douglas Aircraft Company, and Stanford Research International (SRI) simulation program were made available to airline training groups and the industry and airlines were encouraged to develop wind shear training programs. There have been several instances where wind shear training conducted by airline companies enabled pilots to escape severe wind shear encounters and avoid accidents. Two specific cases come to mind; in one case an Eastern flight crew on approach into Atlanta in August 1979 used the procedures recommended in AC-00-50A and taught by their company, abandoned their approach and successfully negotiated a severe wind shear encounter, then landed safely. In the other instance, a United flight crew encountered a strong wind shear and heavy rain right at the rotation point during a takeoff at O'Hare, and using the techniques taught in the United training program they maintained control of the aircraft and were able to safely continue.

The FAA has always recognized that avoidance, whenever possible, should be the primary method for dealing with wind shear, but we also recognize that inadvertent encounters can and will occur, so we are continuing to work on improved systems to attack the problem. We will continue to provide the latest information on wind shear to the aviation community as it becomes available.

With this background to set the stage for our discussions I would like to now address the specifics of our current programs and activities.

One of the key results of our earlier programs was the development and deployment of the Low Level Wind Shear Alert System (LLWAS) at 59 airports. We are in the process of equipping an additional 51 airports. This activity will be completed by the end of next year and will provide alerting service at a total of 110 airports. The LLWAS was developed primarily to warn of wind shears caused by fast moving fronts and thunderstorm gust fronts, and is a surface wind measurement system that cannot remotely sense wind shears at approach altitudes. The system's primary component is a set of mechanical anemometers supported by computer-based data processing and display components. Five remote anemometers are strategically located around the periphery of the airport and their wind data are compared to a single centerfield anemometer. A 15-knot vector difference between the centerfield and any remote site triggers an alert in the control tower and the controller passes advisories to traffic in the airport area. Because this system was developed before the "microburst phenomena" was fully understood, the spacing of the sensors will not effectively detect that type of wind shear. To test the capability of the LLWAS to detect microbursts we have augmented the system at Moisant Airport in New Orleans. Five additional sensors have been added to the anemometer network and the processing algorithms and software have been changed. The test bed system is now installed and operational. We will continue to test and evaluate the modified system over the next year. The results of this test will provide the basis for decisions on modifying the LLWAS. In conjunction with the New Orleans tests, the National Center for Atmospheric Research is conducting further computer simulations and analyses on alternative algorithms and display techniques. We are optimistic that the modifications incorporated in the Moisant system will provide more effective airport coverage, reduce the number of false alerts, and possibly confirm the capability to detect microbursts. Additionally, we are planning to record and archive the data from the system and these data will be analyzed to provide improved siting criteria and increase the climatological data base on wind shear.

Another system which is being implemented this year is the Radar Remote Weather Display System (RRWDS). I hasten to add, however, that this is not a wind shear detection system, per se. Certainly knowledge of the location and movement of severe weather and thunderstorms will serve as a warning of possible wind shears and turbulence. The RRWDS was developed to provide current weather information from National Weather Service radars and FAA long range radars (Air Route Surveillance Radars) to the Center Weather Service Units, FSS En Route Flight Advisory Service locations, and NWS Weather Service

Field Offices. The data are also available to the weather service unit in the Central Flow Control Facility in FAA headquarters. Radar digitizers have been installed in 77 NWS radar sites and 57 FAA radar sites. RRWDS displays are located at 20 air route traffic control centers, the Central Flow Control Facility, 44 en route flight advisory service locations, 2 high activity flight service stations, and 10 weather service field offices. We have procured and installed a total of 134 transmitter site digitizers and 151 displays at 77 locations. The meteorologists at the Center Weather Service Units and the weather service field offices are presently utilizing the radar data in their daily operations. The En Route Flight Advisory Service and FSS locations have fully operating systems, but we have not completed training of our FSS specialists. All RRWDS locations should be fully operational by the end of this year.

The Next Generation Weather Radar or NEXRAD program is an ongoing triagency development of a replacement weather radar that will serve the needs of the National Weather Service, the military, and the Federal Aviation Administration, as well as other Government agencies and the nation. NEXRAD will replace the existing network of weather radars and, for aviation purposes, is expected to provide information on hazardous weather for the nation's en route airspace. Conventional radar measures only reflectivity, i.e., intensity of the return signal. Doppler weather radars have the added ability to measure the radial velocities of particles in the atmosphere. A Doppler radar can, therefore, measure radial wind velocity, a key element in the detection and measurement of severe weather.

A network of radars is planned that will provide weather radar coverage above 10,000 feet throughout the entire country, and possibly provide coverage down to 6,000 feet in nonmountainous terrain. Aviation weather products to be provided by the NEXRAD include: winds, turbulence, thunderstorm detection, storm movement prediction, precipitation intensity, hail detection, frontal movement, freezing levels, mesocyclones/tornadoes, and hurricane intensity and movement.

The NEXRAD validation phase contracts were awarded last year to Raytheon and Sperry for the production of prototype radars; this phase of the program is scheduled for completion in December 1985. Production units are to be installed from 1988 through 1992.

The FAA is a full time participant in this program and is preparing to utilize the NEXRAD weather information throughout the National Airspace System. We have ongoing development programs in weather processors to provide NEXRAD products to the Advanced Automation System for controller use and, through data link services, to the pilot.

NEXRAD, however, will not solve the low altitude wind shear problem in the terminal area. Use of Doppler weather radars for wind shear detection is feasible, and early work by the National Severe Storms Laboratory in the application of single and multiple Doppler radars confirmed the capability to detect and measure the intensity, radial velocities, and spectral width (turbulence) in thunderstorms. The experiments conducted by the Northern Illinois Meteorological Research on Downbursts (NIMROD) provided the basis for Dr. Theodore Fujita's early identification and characterization of the microburst. The results from this Doppler radar research that the FAA and other agencies have sponsored over the last 15-20 years, as well as the continuing analysis of the Joint Airport Weather Study data, reinforce the concept of a terminal Doppler weather radar as a wind shear detection system.

The FAA is actively examining the technical and funding implications of initiating a Terminal Doppler Weather Radar program. The FAA has studied a number of alternatives including: development of a "C" band weather radar, addition of a Doppler weather channel to the ASR-9 terminal ATC radar, modification of commercial Doppler weather radars, and a NEXRAD derivative "tuned" for wind shear detection.

We have a development program for a Terminal Doppler Weather Radar underway. Planning for a terminal weather radar test site at Memphis International Aiport was completed last fall. Lincoln Laboratory has assembled a transportable terminal Doppler test bed radar and has developed processor algorithms tailored for use in the terminal environment. This system, in conjunction with a second Doppler radar operated by the University of North Dakota, will be used to assess radar performance at both on-airport and off-airport locations and to evaluate scanning strategies, data processing, and data display techniques.

The transportable test bed is presently being installed at the Olive Branch, Mississippi Airport which is approximately ten miles southeast of Memphis International Airport. The University of North Dakota "C" Band Enterprise radar is located six miles south of the Memphis Airport. We will also acquire supporting test data from the NWS WSR-57 radar near Memphis, the Low Level Wind Shear Alert System, and an additional thirty unit Mesonet array providing winds, temperature, and pressure measurements. Two flight test aircraft from the FAA Technical Center and the University of North Dakota will participate in the research. The Memphis tests are planned to run for a full year, and will be used to resolve technical issues associated with the operational use of Doppler weather radar in the airport environment.

I would like to mention at this point that the FAA has recently implemented an operational evaluation of microburst forecasts, and detection and warning techniques in the Denver-Stapleton area. We have contracted with the National Center for Atmospheric Research (NCAR) to provide microburst forecasts on a daily basis and provide Doppler radar surveillance and real-time advisories of microburst activity to the control tower. This activity was started on July 7 and will continue through August 15. Radar coverage is provided from 1100 to 2000 hours, Mountain Daylight Time, 7 days a week. The daily forecast is issued at 1000 local time and is transmitted through the Denver Center on the Service A network. United, Frontier, and Continental Airlines have agreed to provide more detailed feedback from their pilots on the efficacy of the advisories. We have already seen several days when there has been significant microburst activity in the vicinity of Stapleton. A thorough analysis of the results of this evaluation will be accomplished when the project is completed. This is the first step in the process of determining how the information supplied by a Doppler radar can be applied to terminal operations.

My comments on radar thus far have largely been confined to ground-based systems, but we are working closely with the National Aeronautics and Space Administration to establish a research effort on the possible applications of airborne Doppler weather radars for wind shear detection and avoidance. NASA has already successfully demonstrated the capability of an airborne Doppler radar to measure wind shear in the absence of ground clutter. This radar was a brassboard, rearward-looking research device that viewed storms at altitude in areas free of ground clutter. A major technical problem that must be addressed is the suppression of ground-clutter returns when the radar is operated in the forward looking mode during approach and landing. There are commercial airborne Doppler weather radars available today, but they basically detect turbulence in precipitation and, to our knowledge, do not measure wind shear--particularly in clear air or dry microbursts.

NASA, as a part of their research, will try to develop improvements for current state-of-the-art airborne radars, to evaluate their capability to detect wind shear. We will continue to support NASA research on airborne wind shear detection systems because we feel strongly that avoidance is key in severe wind shear situations, and an airborne detection system will provide protection in all flight regimes and locales.

Mr. Chairman, I have reviewed most of our major wind shear activities, but the wind shear problem has many facets and there are a few other activities that I should mention before moving into the National Academy of Sciences' study and our plans for implementing their recommendations.

I have mentioned the Joint Airport Weather Study and there are one or two activities closely related to the JAWS program that deserve comment. Drs. McCarthy and Fujita and their teams are continuing to reduce and analyze the wealth of data available from JAWS. The completed analysis of the meteorological data from the study will be used to develop improved wind shear models for simulation programs for training, as well as avionics design and certification. There is a joint NCAR/NASA/FAA/industry committee that has steered the work to develop wind shear models for simulation. It has already held two Government/industry workshops and will continue to provide advice and input on the model development effort and their applications.

NCAR and the JAWS team are also working with our Low Level Wind Shear Alert System program manager in developing improved siting criteria and refined operational algorithms to enhance the LLWAS performance. They are optimistic that redesign of the present system can provide capability to identify microburst occurrences on the airport using the surface detection system.

The JAWS team also collaborated with our Office of Flight Operations in the production of a new videotape on wind shear and the microburst phenomena for pilots, controllers, and meteorologists. Over two hundred copies of this audiovisual training film, entitled "Probable Cause," have been distributed to every major air carrier and the general aviation community. It was also made available to ICAO for reproduction and distribution to non-U.S. carriers. The film stresses the importance of avoidance whenever possible, and describes recommended flight control techniques, and the environmental clues associated with wind shear conditions, particularly microbursts.

As I previously mentioned, we are planning to update Advisory Circular 00-50A with current meteorological information and additional guidance on control techniques. We are working with an Air Transport Association Wind Shear Task Force on this revision.

In November 1983, the Office of Flight Operations released Advisory Circular 120-41 "Criteria for Operational Approval of Airborne Wind Shear Detection Equipment." This circular describes an acceptable methodology for evaluating airborne wind shear equipment. We are already planning to revise that circular with improved wind shear models based on JAWS data and the work of the joint Government/industry committee on wind shear modeling.

There is another specific area that requires further study. Following the Pan American Flight 759 accident at New Orleans, the National Transportation Safety Board issued the following recommendation (No. A-83-18): "Evaluate methods and procedures for the use of current weather information from sources such as radar, Low Level Wind Shear Alert Systems, and pilot reports as criteria for delaying approach and departure operations which would expose the flight to low altitude penetration of severe convective weather."

We do not necessarily disagree with the concept upon which this recommendation is based. Some form of pilot go/no-go decision criteria during periods of severe weather would be highly desirable. Given the status and capabilities of the current systems we believe that the promulgation of such criteria may be premature. To successfully implement criteria, as suggested, requires that we be able to accurately identify the phenomena, particularly in the downburst/microburst case. Presently, we are working on two systems which could possibly achieve the needed reliability and accuracy, the enhanced LLWAS and the terminal Doppler weather radar. Wind velocity thresholds have been proposed as a possible criterion, but generally wind shear velocities go through a threshold rapidly and intensify over a very short period of time. This is especially true of thunderstorm generated wind shear conditions. We feel it is more important to recognize the downburst/microburst phenomena and issue advisories on that basis. It appears vital that recognition occur at the formation stage so the advisory is timely, with minimum false or unnecessary advisories. The FAA will continue to work on this problem to provide the best possible guidance to pilots and contollers during periods of severe weather.

Mr. Chairman, I believe that completes my comments on the history and highlights of the FAA wind shear program. As you have requested, I will now move on to the National Academy of Sciences' recommendations and our plans for implementing them. I think it is also appropriate to note here that the National Academy study contains an excellent review of wind shear detection technologies in Chapter 2, "Low Altitude Wind Shear."

The National Academy study published last November made 19 recommendations, grouped into four categories: General, Detection and Prediction, Aircraft Performance and Operations, and Research. In general, the FAA accepts the recommendations of the study group and we believe that our present wind shear programs are responsive to most of their recommendations.

1. <u>Need for An Integrated Wind-Shear Program.</u>

"To provide for the safety of the flying public, the FAA and the aviation industry should address the many facets of the low-altitude wind shear problem as a whole. The FAA should develop and implement a coherent and sustained program for coping with the educational, meteorological, technological, and operational aspects of low-altitude wind shear hazards."

The Weather Coordination Program Staff has been designated to serve as the focal point for our wind shear activities and a staff member, Mr Myron Clark, has been named as the Wind Shear Program Coordinator. Mr. Clark will develop an integrated wind shear program plan that will serve to coordinate the activities of the various wind shear related programs in the FAA and elsewhere. Through the program plan we can ensure that the FAA follows a sustained and coherent plan in addressing the wind shear problem.

2. <u>Wind Shear Education Program.</u>

"The FAA and the industry should prepare and disseminate as widely as possible updated and authoritative information on wind shear. Informational materials should stress avoidance of wind shear and should describe flight control techniques for recovery from encounters. The information should encompass all types of aircraft, with appropriate guidance for each class. It should include recommendations on the most effective means of training pilots.

The FAA should revise and update its 1979 Advisory Circular (AC 00-50A) on wind shear and the Airman's Information Manual (AIM) to present the latest information, including detection techniques, alerting and warning procedures, effects of wind shear on aircraft performance, and procedures for recovery from wind shear encounters."

As I indicated earlier, the FAA is concerned about pilot awareness and understanding of the wind shear phenomena and appropriate pilot actions during an inadvertant encounter. The Office of Flight Operations considers pilot education, as well as pilot training on wind shear, a priority task. We will continue to make an effort to reach out to the aviation community through our normal channels of communications, such as: Notices to Airmen, Letters to Airmen issued by both the Air Traffic Service and the Office of Flight Operations, Safety Bulletins, Operations Bulletins to commercial operators, the General Aviation Accident Prevention Program, which has full time safety specialists assigned to the program, Biennial Flight Reviews (to which we are considering adding a weather training segment), and the Airman's Information Manual (AIM). In regard to the AIM, a task group of the National Airspace Review has just completed a staff study and has developed recommendations for reconfiguration and simplification of that publication. Also, the Air Traffic Service is presently coordinating a contracted study on how the FAA can improve the availability, readability, and salability of the AIM.

We support and cooperate with public communications media by providing current information on aviation issues.

The Office of Public Affairs is in the process of producing an audiovisual on aviation weather in general, and Flight Operations is planning to update "Probable Cause", our wind shear training film.

Air Carrier Principal Inspectors will continue to stress the importance of wind shear awareness in recurrency training and flight reviews. The Office of Flight Operations' General Aviation Division has an active pilot safety seminar program and will continue to make current information on wind shear available to the general aviation community. It will continue to work closely with the various general aviation associations, such as the Aircraft Owners and Pilots Association and the General Aviation Manufacturers Association, to provide the latest published information on wind shear.

The FAA recognizes this as a problem area and we are working on it.

3. Pilot/Controller Communications.

"The FAA should promote the use of standardized terminology and improved communications between flight crews and control towers. A standardized system of pilot reports (PIREP's) should be developed for reporting low-altitude wind shear encounters. PIREP's should be mandatory and should include a report of the location, severity, and nature of the shear encountered--in consistent, standardized terminology. Controllers should communicate such reports to all flight crews in the vicinity. In addition, techniques for the direct broadcast to pilots of wind shear data from LLWAS or other sensors should be investigated."

The acquisition, dissemination, and standardization of format and terminology of PIREP's have been, and continue to be, an important part of the development of an effective Aviation Weather System. There is an ongoing effort, in concert with the National Weather Service (NWS) and concerned pilot organizations, to improve PIREP procedures. The FAA has provided further guidance to controllers on the solicitation and retransmission of pilot weather reports, including wind shear report, and the procedures for wind shear advisories at Low Level Wind Shear Alert System (LLWAS) equipped airports, in the latest revisions to FAA Handbook 7110.65C, "Air Traffic Control," and FAA Orders 7110.84, "Terminal Area Pilot Weather Reports (PIREP's)," and 7210.3-1222, "Low Level Wind Shear Alert System (LLWAS)."

Mandatory pilot reporting of wind shear encounters appears, on the surface, to be an excellent way to force an improvement in this area. However, "mandatory" implies regulatory action and, by definition, must be enforceable. It is evident from the National Academy of Sciences' report that we are not currently in a position to determine independently whether or not pilots are reporting all wind shear encounters. The FAA will continue to encourage pilots to report wind shear encounters expeditiously.

Direct broadcast to pilots of wind shear data from LLWAS or other sensors is planned when MODE-S is available. However, the FAA will investigate the technical and operational feasibility of the direct broadcast of such data via an interim system provided no human interpretation of sensor data is needed.

4. Wind Shear Detection System Development.

"The FAA should select a site to test direct and remote-sensing techniques in a complete system for detecting low-altitude wind shear and for providing information to pilots and controllers and to test the use of the information in the air traffic control system. The test site should be at a major airport where wind shear conditions are relatively frequent."

The FAA feels this recommendation has been acted on with our establishment of the Memphis and New Orleans test sites.

Recommendations 5 and 6 in the study dealt with the Low Level Wind Shear Alert System improvement and recording of LLWAS data. Since we have already described our activities that address these recommendations, I will not repeat that discussion here.

7. Use of Available Radar Data.

"The existing network of weather radars, operated by the NWS, should be used more effectively to judge the likelihood of wind shear conditions. These radars detect rain showers, thunderstorms, and phenomena often associated with wind shear. Information from weather radars should be made available to air traffic controllers in a timely and easily understandable fashion."

In developing this recommendation, the committee was addressing the fact that many major airports are within the coverage area of a National Weather Service weather radar, and that controllers in the towers at these airports should have access to a display of the information from these radars. If such information were available to the tower controllers, they could then better advise pilots of the weather situation in the immediate airport area. The committee felt that the FAA was not taking advantage of useful information that exists and would be relatively inexpensive to provide.

The FAA will determine the feasibility of providing existing NWS radar weather information to control tower cabs so that controllers can provide the latest severe weather warnings to pilots prior to departure or landing. This would require the installation of a weather radar display in an operating tower cab, and we believe some processing of the information would be required to allow rapid interpretation of the meteorological phenomena. It should be pointed out, however, that existing FAA terminal radars already provide some indication of severe weather and, depending upon the relative location of the NWS radar, may provide better severe weather information than the NWS radar; also, the new ASR-9 will have a weather channel.

Recommendations 8 through 11 dealt with accelerating NEXRAD development, developing an Airport Terminal Weather Radar, and Airborne Sensors. These programs have been discussed previously.

Recommendations 12 and 14, which must be considered together, are the most difficult to respond to because they are so all encompassing and the work that has been accomplished in this area was very comprehensive.

12. Wind Shear Effects on Flight Characteristics.

"The FAA should sponsor analytical and simulator investigations to determine:

- The wind shear penetration and recovery capabilities of transport aircraft, based on various onboard detection, guidance, and control systems.

- The effects of wind shear on various typical categories of general aviation aircraft and helicopters so that authoritative information on their response characteristics and piloting techniques in wind shear can be provided."

The FAA believes that the first step in assessing the effects of wind shear on aircraft performance requires an accurate determination of wind shear profiles or models. Once we have established an acceptable set of models, a comprehensive evaluation should be accomplished through simulation, both fast-time and piloted. As I mentioned before, we are cooperating with the National Center for Atmospheric Research, NASA, and industry in the development of models; and in conjunction with the model development, the group will propose guidelines for their implementation and application.

For training and equipment design and certification the models are critically needed, but the more practical approach is the early developmment of better forecasting techniques (particularly for thunderstorm, downburst, and microburst forecasts) and the development and deployment of detection and avoidance systems.

We think that our current Advisory Circular on Low Level Wind Shear and the planned update that a joint FAA/industry working group is developing still identifies the best technique for maximizing aircraft performance in wind shear. I have already cited examples where properly applied piloting techniques have been successful. We will continue to work with the aviation industry to perfect our knowledge in this area.

The FAA, in conjunction with NASA, Douglas, Boeing, and SRI International, carried out extensive simulation studies that addressed airborne displays, instrumentation, and procedures for aiding pilots in coping with unexpected wind shear during approach and takeoff. This was a thorough, 4-year effort involving a wide spectrum of guidance and control aids for transport category aircraft. There have been no significant breakthroughs in either basic aerodynamic design or onboard guidance and control systems since these studies were completed in 1979. Because of this, the FAA will be working very closely with NASA and various user groups to define more precisely the work that needs to be accomplished in this area. One user group, the Air Transport Association, has already formed a Wind Shear Task Force to address issues such as this. Our major concern in this area is that the extensive and rigorous experimentation recommended would require significant resources and would result in only a very limited, if any, increase in the wind shear knowledge data base. This, by itself, is significant, but becomes much more significant when coupled with the fact that there can still be instances of severe wind shear encounters that would not be survivable. This is the reason that the FAA stresses avoidance as the optimum method for dealing with wind shear and would prefer to see resources invested in the development of an operationally acceptable airborne detection system. Such a system would provide wind shear avoidance capability in all aircraft operating environments and in all locations worldwide.

14. <u>Guidance and Control Aids</u>.

"Onboard sensors and guidance aids should be evaluated in a systematic manner to determine their merits for future development and for possible retrofit in existing aircraft. These include flight director modifications, ground speed/airspeed flight mnagement systems, vertical-acceleration sensors, and energy-rate sensors. Angle-of-attack indicators should be added to the cockpit instrumentation of transport aircraft for use in maneuvering through wind shears. Angle of attack should be provided either as a separate variable or as an input to other command displays. Sensors should provide flight crews with a voice warning of a hazardous wind shear."

The evaluation of onboard sensors and guidance aids (Recommendation 14) is an integral part of Recommendation 12, and the discussion of that recommendation for the most part applies here as well. Regarding the recommendation that angle-of-attack indicators be added to the instrumentation of transport aircraft or be provided as an input to other command displays, it should be pointed out that angle-of-attack information is utilized in our present generation of transport aircraft. Angle-of-attack indicators are not standard instrumentation, but the inputs from angle-of-attack systems are used by a number of flight directors, flight management systems, stall warning systems (stick shaker), and wind shear detection and guidance systems. The FAA will continue working with the Air Transport Association Wind Shear Task Force, NASA, and other advisory groups to address the issue of angle of attack and its application to the wind shear problem.

13. Aircraft Operating Procedures.

"The FAA should ensure that air carriers and other commercial operators instruct flight crews on what to do if they inadvertently encounter a low-altitude wind shear during takeoff or landing. In addition, the FAA should encourage operators of jet aircraft to incorporate in their manuals the operating procedures recommended in its advisory circular on wind shear. Aircraft manufacturers should recommend configuration-change sequences (gear, flaps, power, spoilers, etc.) that provide the highest probability for recovery from a wind shear encounter. Pilots should be taught to exceed the normal maximum thrust limits and to go to emergency thrust when necessary."

The Office of Flight Operations has issued air carrier operations bulletins that provide guidance to all carriers and commercial operators with reference to crew training and operating procedures for wind shear encounters.

The required FAA approved airplane flight manual (AFM), which accompanies all certificated aircraft, is not suited for presentation of wind shear procedures. The FAA specifically avoids inclusion of information relating to airmanship in the required AFM. Individual commercial air carriers are empowered to publish their own crew operating procedures manuals (i.e. airplane operations manual (AOM)) that incorporate all FAA required flight manual information, plus other information appropriate to their individual operations. These operations manuals often provide information related to airmanship, and carriers are encouraged to include best known wind shear procedures. For other operators of turbine powered aircraft who use only the FAA approved AFM, the FAA Accident Prevention Program currently disseminates information concerning wind shear in pamphlets, films, and discussions at pilot forums. Accident Prevention Specialists discuss the phenomena and best known techniques and procedures at well attended seminars.

General aviation operators are encouraged to become familiar with wind shear advisory material such as AC 00-50A. Instructors are encouraged to observe during biennial reviews proficiency and knowledge concerning wind shear. The FAA believes this program provides the best means for disseminating information relating to airmanship.

15. Standardization of Wind Shear Models.

"The FAA should sponsor a program to develop and define standardized models of wind shear based on the latest meteorological data. These models are required for design and certification of aircraft subsystems and for use in training simulators. The FAA should include other Government agencies, aircraft manufacturers, commercial operators, and any other interested parties in the program."

This recommendation is being acted on. As I mentioned earlier, we are continuing to support the reduction and analysis of the JAWS data base to develop standardized wind models for training and equipment design and certification.

An additional activity, sponsored by the Office of Flight Operations, is currently in progress to investigate the incorporation of wind shear profiles and associated training techniques into all categories of flight simulators ranging from general aviation to transport types.

16. Certification of Onboard Systems.

"The FAA should update its certification requirements for airborne wind shear alerting, flight guidance, and automatic control systems."

FAA's Office of Flight Operations has recently released Advisory Circular 120-41 "Criteria for Operational Approval of Airborne Wind Shear Detection Equipment" and will update this advisory circular with the latest wind shear data when the final analyses of the JAWS data set are published. The appropriate FAA offices will reexamine current guidance material on the certification of flight guidance and automatic control systems to determine if revisions are required.

17. Wind Shear Simulation Training.

"The FAA and the industry should cooperate to investigate new and innovative ways to make available the best possible simulation training for wind shear to the largest possible number of pilots, including general aviation pilots."

The FAA has taken steps to facilitate improved wind shear training for user groups. FAA, NASA, and the National Center for Atmospheric Research have sponsored workshops with industry to make available the most current wind shear data. The basic objective of these workshops was to give the various user groups the opportunity to review the format, quantity, and quality of the data, and consider possible training applications of the data sets. Since each user has unique requirements for data, based on their individual training objectives and their individual simulation capability, the data must be examined in light of its most cost-effective applications. FAA will continue to make available to the aviation community all information and data resulting from future research and experimentation.

18. Effects of Heavy Rain.

"Investigations should continue on how heavy rain affects the low-speed aerodynamic characteristics of aircraft. Particular attention should be paid to the possible adverse effects of heavy rain on aircraft lift, performance, and controllability, including its effects on wind shear detection and flight sensor systems."

FAA agrees with this recommendation. NASA has an ongoing program to investigate the effects of heavy rain on airfoil efficiency and aircraft performance. Recent NASA experimentation has established that heavy rain appears to reduce lift in a wind/water tunnel environment, but this experimentation needs further refinement and testing. FAA is providing support and guidance to NASA's research and will consider appropriate action when NASA's experiments have been completed.

19. <u>The Nature of Low-Altitude Wind Shear.</u>

"More must be learned about the various kinds of wind shear and the meteorological conditions that cause or are associated with them. This knowledge is needed to reduce the hazards represented by low-altitude wind shear. Research should include additional field observations and the construction of theoretical models over the relevant scales -- from about 1,000 feet to 10-20 miles and from minutes to hours.

The existing body of data obtained by various research programs should be reexamined and augmented, at an appropriate time, by a field program in the humid southeastern United States. Analyses of the data obtained from the JAWS Project should be used to plan any new field investigation. Basic research into the origins of strong thunderstorm downdrafts and possible forecast methods should be an important component of any new program."

FAA will consider the requirements for additional wind shear research after an assessment has been made of the availability of data from planned and ongoing meteorological research activities. In response to Recommendations 5 and 6, additional data from the archiving of LLWAS measurements will be analyzed and incorporated in existing wind measurement data bases. Additionally, radar and surface mesonet data will be acquired and analyzed as part of the Memphis terminal Doppler radar tests. In the longer term, the National Oceanic and Atmospheric Administration has established programs that will provide substantial data sets, both surface and upper air, for analysis and study. The Stormscale Operational and Research Meteorology (STORM) Program, currently being planned by the National Center for Atmospheric Research and supported by the National Science Foundation, NOAA, NASA, FAA, DOD, and university research groups, will contribute to the knowledge of mesoscale convective activity and forecasting techniques to provide near real-time response to small scale severe weather conditions.

This finishes my discussion of the National Academy of Sciences' study, and before concluding my remarks I have one last topic to discuss. Some pilot groups have recommended that accurate knowledge of the horizontal shear that the aircraft will fly through would facilitate safer pilot decisions. We have tasked the FAA Technical Center, as part of the LLWAS enhancements program, to investigate if the system software could be programmed to extract this information from the LLWAS data. Since most wind shears are short-lived and grow rapidly in intensity, the best procedure and the one we recommend is avoidance; but we will continue to explore avenues to provide the pilot with full and accurate information on the airport weather environment. We believe that the FAA wind shear program that is being conducted in concert with other agencies, including NASA, NSF, NWS, NCAR, Environmental Research Laboratory (ERL), Wave Propagation Laboratory (WPL), National Severe Storms Laboratory (NSSL), Air Force Geophysical Laboratory (AFGL), University of Chicago, University of North Dakota, South Dakota School of Mines, Lincoln Laboratory, and others, is addressing the recommendations of the National Academy of Sciences and will provide successive improvements in our understanding of the physics of microbursts, our ability to forecast and detect these phenomena, and also availability to provide improved information to both controllers and pilots on the location and degree of hazard of a microburst. The ability to warn accurately of the presence of wind shear and the development of the phenomena will provide a significant improvement in flight safety.